Ability to Overcome Initial Impulses to Motivational Stimuli Evidenced by Prefrontal Cortex Activity

AP Research

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Contents

Introduction

Defining Self-Control Through Intertemporal Choice

During adolescence, emotions are heightened, causing impulsivities to be more difficult to resist. An inability to self-regulate places individuals, particularly adolescents, at higher risk for preventable manners of childhood and adolescent mortality, including suicide, addiction, and subsequent substance abuse (Casey & Caudle, 2013). Self-control is often defined with regard to an individual's ability to inhibit impulses that may prevent the individual from achieving certain objectives (Gillebaart, 2018). In particular, how an individual responds to conflicts between short-term and long-term goals appear to be the primary aspect able to differentiate low self-control and high self-control.

Existing research focuses on why subjects tend to pursue immediate gratification, or choosing the immediate reward rather than a greater reward at a later time (Kim & Lee, 2010). Contrary to immediate gratification, delayed gratification is exemplified when individuals are able to practice restraint in the face of temptation, an action that signals effective sign-control (Ding et al., 2021; Green, 1982). The evaluation and weighting of smaller, immediate rewards versus larger, delayed rewards is defined as intertemporal choice (Keidel et al., 2021). Through a process known as intertemporal choice, the urge to practice immediate gratification can be explained by delay discounting, in which an individual believes the value of a reward decreases over time. Under the notion of delay discounting, an individual would prefer to receive ten dollars today over ten dollars in one month (Kelley et al., 2019). This can be attributed to how the individual responds to risk: there is less certainty that the individual will receive the aforementioned ten dollars after a month than ten dollars immediately, so it is common to prefer the nearest reward (Green et al., 1994).

From a cognitive perspective, the concept of self-control is frequently studied in relation to the prefrontal cortex, the frontal area of the brain that regulates decision-making and impulse control (Kelley et al., 2019). While the prefrontal cortex is directly involved in an individual's ability to self-regulate, subcortical regions of the brain that regulate reward processing (i.e., the ventral striatum) also holds weight in how much self-control an individual is able to demonstrate (Gillebaart, 2018). Therefore, in studying self-control, it is critical to take into account the cognitive mechanisms underlying behavior to accurately understand the influences that drive self-control.

Previous Research

Research of delay discounting has been conducted on a broad range of age groups. In particular, one study examining the rate of delay discounting, or choosing the immediate yet less valuable reward over the larger reward after a longer period of time, found that three different age groups—children (M = 12.1 years), young adults (M = 20.3 years), and older adults (M = 67.9 years)—all showed delay discounting (Green et al., 1994). However, the three groups tested showed different rates of discounting, with the group having the highest discounting rate being children and the group with the lowest discounting rate being older adults. While these findings suggest that the rate of delay discounting can be expected to decrease as an individual's age increases, additional considerations may alter rate of discounting. For instance, the study notes that longer delays may alter an older adult's decision, citing that the prospect of surviving long enough to receive a delayed reward may drive the older individual to retain a higher rate of discounting than previous trends (Green et al., 1994). The multitude of variables that influence

an individual's rate of delay discounting similarly affect the amount of self-control an individual demonstrates.

Another significant factor that shapes an individual's ability to successfully self-regulate is anticipated emotions, which can change one's original path of behavior (van der Schalk et al., 2012). How an individual believes they will feel as a result of completing or forgoing a task can serve as an indicator of the individual's actions. There is often internal conflict when one is presented with motivational stimuli that are perceived as negative—for example, a chocolate cake for someone who is on a diet. If the person is tempted by the cake, there are two basic directions their decisions and emotions may adopt, the first being acting on that temptation, which would fulfill their craving for the cake, yet produce a negative anticipated emotion such as guilt. On the other hand, the person could resist the cake, which would fail to fulfill their craving for the stimuli, yet produce a positive anticipated emotion such as pride for adhering to their diet (Kotabe et al., 2019). In addition, the amount of emotional weight the individual places on their anticipated emotions can guide researchers in forming predictions of an individual's capacity for self-control. Furthermore, parallels of how an individual responds to anticipated emotions and their immediate, initial emotions can be drawn. It was found that individuals who placed a higher significance on their initial emotions tended to "give in" to their initial impulses and demonstrate a failure of self-control (Hofmann & Kotabe, 2021).

Role of the Prefrontal Cortex in Self-Control

By studying the prefrontal cortex, the area of the brain responsible for regulation of decision-making and impulse control, researchers are able to pinpoint specific cognitive influences on an individual's ability to self-regulate (Kelley et al., 2019). While there are

opposing theories of how activity in the prefrontal cortex is correlated with self-control success, researchers have cited that the ability to exercise self-control is largely dependent on inhibitory and excitatory neurotransmitters in the brain. Inhibitory neurotransmitters do not stimulate the brain, instead inhibiting neurons from firing off action potentials, or chemical messages. On the contrary, excitatory neurotransmitters stimulate the brain by reinforcing the firing of action potentials (Boto & Tomchik, 2019). Previous research has found that failure of a subject to overcome impulses can be correlated with greater activity in the inhibitory regions of the prefrontal cortex as it will tax the brain significantly (Chester, et al., 2016). However, a review of experiments using non-invasive brain stimulation techniques found that increased stimulation of the prefrontal cortex could instead be correlated with more successful self-regulation (Kelley et al., 2019). Thus, self-control is heavily affected by the location and extent of stimulation rather than merely the stimulation on its own. Specifically, certain types of stimulation may affect self-control; for example, brain wave frequencies of beta and theta may impact the balance of inhibitory and excitatory neurotransmitters, altering self-control patterns in an individual (Porjesz & Begleiter, 2004).

Research Gap

Beta and theta waves have been prevalent in studies involving alcoholism (Porjesz & Begleiter, 2004). In particular, researchers have found that the same inputs that generate beta waves also stimulate inhibitory neurotransmitters (Sherman et al., 2016). The ratio between excitatory and inhibitory neurotransmitters has been cited as critical for the functioning of neural circuits (Chester et al., 2016). Researchers are particularly interested in investigating the effect beta power could have on pyramidal neurons, or excitatory neurons that populate the mammalian

cortex and can stimulate the brain through the firing of action potentials (Spruston, 2008; Nelson et al., 2006). In a study examining beta activity in relapsing alcoholics and nonrelapsers, it was found that relapsers experienced irregular patterns of beta wave firing. It was also noted that rapid beta power could be used as a predictor of relapse (Porjesz & Begleiter, 2004). However, because the increase in beta power was a variable recognized in both the group of alcohol relapsers *and* in the offspring of those identified to be at higher risk for alcohol dependency, it can be concluded that an increase in beta power is present as a "trait" variable, or a variable that is consistent and stable, such as a genetic predisposition to alcohol-dependence rather than as the result of self-regulation failure. A "state" variable, converse to a trait variable, reflects how an individual reacts in specific situations. Examining beta activity as a "state" variable is more conducive to understanding how the amount of self-control an individual possesses in a given time and under certain conditions may vary. Thus, there remains a gap in the current research with respect to the relationship between beta activity in an individual in a particular and recent time frame and the individual's ability to practice self-control.

Research Goals and Objectives

This study addresses the gap in the current research by centering on an individual's ability to resist *immediate* temptations, requiring participants to make a decision reflecting their self-control in a short period of time. With the use of an electroencephalogram (EEG), this research study attempts to assess the relationship between brain wave frequencies and self-control exhibition. A two-part quantitative methodology was used in order to gain insight into the question of: To what extent do brain wave states affect an individual's ability to overcome initial impulses to motivational stimuli? Prior research over the five brain wave states supports

this study's hypothesis that activation levels of beta waves (12-28 Hz) will increase in those demonstrating more self-control while activation levels of theta waves (3.5-7.5 Hz) will show an inverse relationship, appearing more frequently in individuals demonstrating lower self-control. In particular, the goal of this research project is to successfully identify the relationship between brain wave states and an individual's short-term self-control.

Methodology

Research Design

This study was conducted using a two-part quantitative methodology. The first part of the study included a twenty-five-question Likert survey in which participants self-reported four measurable subcategories of self-control. The second part of the study required participants to complete an intertemporal choice task. In order to collect the brain wave data of the participants while they completed the intertemporal choice task, participants were instructed to wear the Flowtime Biosensing Meditation Headband, which functioned as a neuroimaging machine and is further detailed in the section "Justification of Research Methods" below. Every participant taking part in the intertemporal choice task had previously completed the preliminary Likert scale survey, though not every participant that completed the survey decided to continue participation in the study and engage in the choice task. Thus, only the data from individuals who had completed both the self-report Likert survey as well as the intertemporal choice task was used to draw conclusions in this study's results and analysis.

Figure 1

2-part quantitative methodology

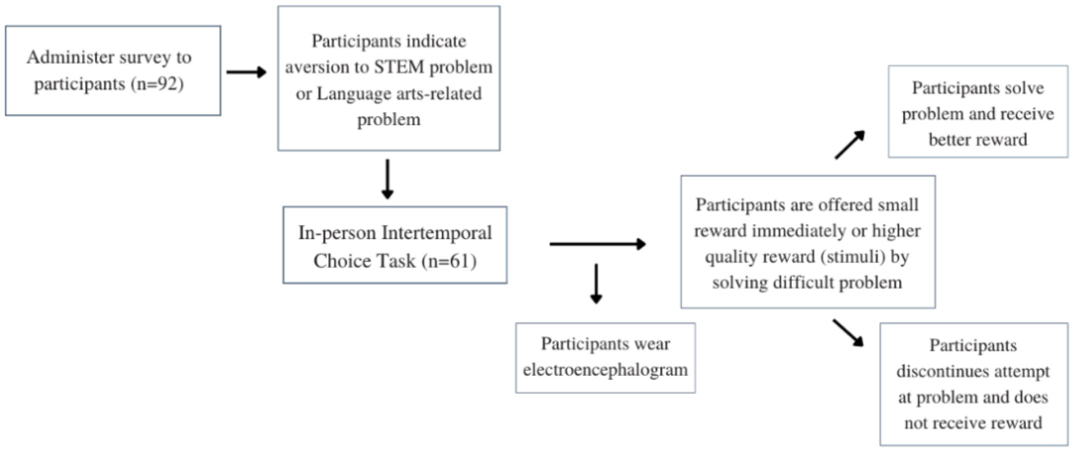


Figure 1: This figure shows the chronology of this study's methodology. The two parts of the methodology include a self-report Likert survey and an intertemporal choice task.

Subjects

Ninety-two individuals participated in the Likert survey ahead of the in-person task. Participants constituted a convenience sample. Thirty-one participants did not complete the second part of the experiment (choice task) due to either a lack of time or interest from participants. Thus, the final sample group amounted to sixty-one participants (n=61; 50% female, 50% male; 100% 16-18 years old; 49% Asian, 46% Caucasian, 5% Other).

Self-report Survey

Participants were asked to complete a self-report survey prior to the in-person tasks. Questions on the survey involved statements such as "Rate how closely the following statement relates to you: I trust myself to make good decisions." The twenty-six-question survey was organized into four categories: ability to resist temptations, ability to ignore short-term distractions in pursuit of long-term goals, importance placed on decisions, and extent to which

external factors such as other people's decisions affect their own choices. Participants could answer on a range of "strongly agree" to "strongly disagree," which correlated with the numerical scale of 1-5, with 1 indicating "strongly disagree" and 5 indicating "strongly agree." Questions 18, 19, 20, 21 were reverse coded, where a point-value of 1 indicated "strongly agree" rather than "strongly disagree." This is due to the aforementioned questions being negatively phrased (e.g., 21 - "If I am not making progress toward my goals, I frequently stop trying") so that agreeing with the phrase suggested lower self-control while disagreeing aligned with the score value assigned for the twenty-one other questions. The survey also contained one additional question requiring participants to indicate the subject more difficult for them: STEM or English/Language Arts. This question pertained to the second part of the methodology, the intertemporal choice task, but held no significance in the self-report survey. Thus, the question was not assigned a point value and scores of the self-report survey ranged from 41 to 150.

Intertemporal Choice Task

There were two primary objectives that the intertemporal choice task intended to achieve: determine whether individuals were accurate in their perception of their self-control and determine whether there was a relationship between brain wave activity in the prefrontal cortex and the amount of self-control individuals possessed.

Intertemporal choice tasks often involve monetary incentives, namely presenting an individual with the choice of a monetary sum today versus a larger amount in one week (Figner et al., 2010; Keidel, 2021). However, this study centered on an individual's ability to reject *initial* impulses, thus, an emphasis was not placed on how varying amounts of time influence an individual's choice of reward, instead focusing on how willing an individual was to work for the

reward (McClure et al., 2007). Thus, for the purposes of this study, chocolate was used as an incentive over money. The reward of lower value was the Hershey Bite-Size Chocolate Candy while the higher-value chocolate was the Ghirardelli Chocolate Square Candy. The intertemporal choice task consisted of five steps. To begin, participants wore an electroencephalogram. Participants then received a one-page test, specifically math (n=37) or English (n=24). The type of test distributed to participants was determined by which subject participants indicated was more difficult for them through a question in the Likert survey. Participants then received instructions with the available options: complete the test within the five-minute time limit, receiving the higher value chocolate, or quit and receive the lower value chocolate.

Justification of Research Methods

Electroencephalography (EEG) is primarily used in healthcare to examine conditions related to the brain, such as epilepsy. EEGs are noninvasive and often valued by researchers for their ability to record brain activity in real-time (Kelley et al., 2019). EEGs can measure electrical activity in the brain using electrodes that are placed on the scalp. These electrodes are able to detect changes in the electrical charge of cells in the brain that transmit information, or neurons, when a stimulus causes an abundance of neurons to fire, or increase in activity simultaneously (Britton et al., 2016; Light et al., 2011). The result of an EEG is presented as brain waves that fluctuate in intensity throughout the trial. Brain waves are classified by their frequency, or the number of waves that complete a cycle in a given amount of time, and there are five primary brain wave frequencies: delta (1-3hz), theta (3.5–7.5 Hz), alpha (8.0–11.5 Hz), beta (12–28 Hz), and gamma (28.5–50.0 Hz) (Posada-Quintero et al., 2019).

For this study, the Flowtime Biosensing Meditation Headband was used. This EEG was chosen for its ability to provide a breakdown of the five brain wave frequencies and track activity in the right and left hemispheres of the brain. Each frequency is associated with specific states of consciousness; for example, delta waves are the slowest wave frequency and are commonly observed during sleep. Wave frequencies that are higher are predominantly believed to yield increased activity and function of the brain (Porjesz & Begleiter, 2004). This is evident in alpha, beta, and gamma waves, which are observed when an individual is awake, and in delta and theta waves, which are observed during periods of rest. This study in particular examines beta and theta waves, which have previously been identified to be prominent in studies involving alcohol dependence (Porjesz & Begleiter, 2004). In previous research evaluating the relationship between beta wave frequencies and alcohol dependence, it was found that the alcohol-dependent group showed increased activity in band frequencies beta 2 (16–20 Hz) and beta 3 (20–28 Hz). Similarly, in the alcohol-dependent group, beta wave power appeared to be disrupted, with beta activity firing unpredictably, the cause of which was determined to be a disruption in the balance between inhibitory and excitatory neurotransmitters in the prefrontal cortex (Rangaswamy et al., 2002; Porjesz & Begleiter, 2004). A similar trial was conducted in which theta power/intensity in groups of alcohol-dependent individuals and control subjects were examined. The study concluded that theta power was higher in alcohol-dependent groups (Rangaswamy et al., 2002). The use of an EEG in the aforementioned studies confirmed that alcoholic dependence is contingent on the balance between excitatory and inhibitory neurotransmitters, which can be altered by variations in brave wave frequencies (Rangaswamy et al., 2002).

Results

After performing the methodology detailed above, there were three datasets available: the self-report scores from the Likert survey, brain wave frequencies from the EEG, and each participant's decision when presented with the chocolate and the test, yielding two groups: the group that quit and the group that ran out of time. To evaluate whether there was a statistically significant difference between the quit group and the group that ran out of time, an independent samples *t*-test was performed to compare the persistence of participants to their beta wave frequency. The analysis produced a significant *t* value ($t_{(59)} = 1.741$, $p = .043$). An examination of the means revealed that the participants that ran out of time had higher beta wave frequencies than the participants who quit the task. An analysis of the persistence of participants to their theta and delta wave frequencies produced a significant *t* value at the p = .06 and p = .07 levels of significance, respectively. Table 1 below demonstrates activation levels of all five brain wave frequencies in comparison to the two groups derived from the intertemporal choice task.

Table 1

T-test comparisons of brain wave frequencies by task groups

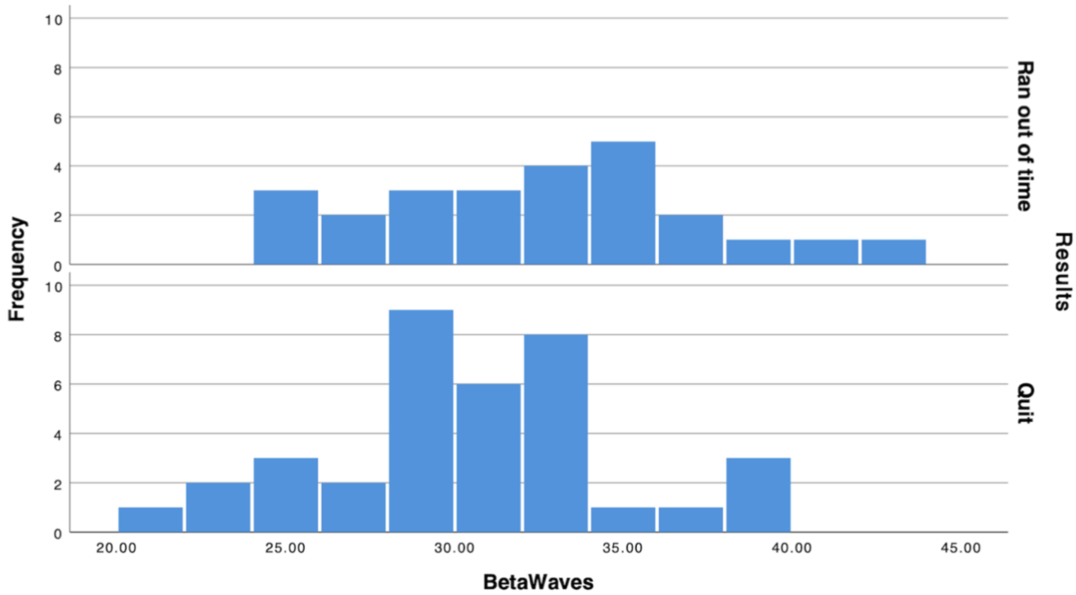
Measure	Quit		Ran out of time		t(59)	P	Cohen's *d*
	M	SD	M	SD			
Beta Waves	29.972	4.299	32.040	4.920	1.741	0.043*	0.453
Alpha Waves	25.667	2.242	24.760	3.270	-1.204	0.236	-0.335
Theta Waves	25.444	3.460	23.960	4.108	-1.526	0.066	-0.397
Delta Waves	10.639	1.477	10.000	1.958	-1.453	0.076	-0.378
Gamma Waves	8.278	2.386	9.200	4.173	0.997	0.325	0.285

*p < .05.

Furthermore, participants in the quit group demonstrated less variance in activation of beta waves in comparison to the group that ran out of time. Frequency of participants experiencing beta wave activation also appeared to peak between beta wave frequencies of 25% and 35% in the quit group, as exhibited in Figure 2.

Figure 2

Frequency of beta wave activation levels in task groups



To evaluate whether participants were accurate in their prediction of how much self-control they believed they possessed, correlation tests were used to evaluate whether there was a correlation between the score participants gave themselves and the decision they made during the intertemporal choice task. The self-report survey was categorized into four different sections: participant's confidence in their ability to resist temptations, participant's capability of ignoring short-term distractions to pursue long-term goals, weight/importance participant places on their decisions, and extent to which external factors influence participant's decisions.

Table 2

Intercorrelations for Choice Task Decision by Self-Report Variables

Variable	Confidence	Capability	Importance	Extent
Participant Decision	0.053	0.087	0.084	0.237

Note. *p < .05.

A bivariate correlation test was conducted to determine whether the score individuals received in the four survey variables were correlated to the individual's decision in the intertemporal choice task. There was no correlation found between confidence in ability to resist temptations ($r(59) = .053$, $p < .05$), capability to ignore short-term distractions to pursue long-term goals ($r(59) = .087$, $p < .05$), weight/importance participant places on their decisions ($r(59) = .084$, $p < .05$), or extent to which external factors influence participant's decisions ($r(59) = .237$, $p < .05$).

Analysis

Effect of Neurotransmitters on Brain Wave States

Beta and theta waves were the two primary brain waves hypothesized to differ in activation levels for the two task groups. These two brain waves were chosen in particular due to their relationship with inhibitory and excitatory neurotransmitters. Neurotransmitters, or chemical messengers, are used as communication between nerve cells known as neurons. Neurons are able to release neurotransmitters into a space between a sending neuron and a receiving neuron known as the presynaptic gap (Purves et al., 2001).

Previous research found that disturbing the balance of inhibitory and excitatory neurotransmitters can lead to the development of neural disorders (Selten, 2018). Self-control can also be disrupted by an imbalance of inhibitory and excitatory neurotransmitters. In a study

comparing theta power in alcohol-dependent groups and control groups, it was found that the alcohol-dependent group possessed higher theta power across all scalp locations in comparison to the control group (Porjesz & Begleiter, 2004). This is reflected in Table 1, which demonstrated that theta wave activation was higher in the group exemplifying lower self-control, the quit group. An increase in theta power is able to drive addictive processes because information processing is impaired in alcohol-dependent groups, particularly taking effect in the central nervous system, reflecting an imbalance between the two types of neurotransmitters (Rangaswamy et al., 2002; Porjesz & Begleiter, 2004). On the contrary, beta waves appeared higher in the group that ran out of time, or the group with higher self-control, rather than the group that quit, or the group with lower self-control; furthermore, participants most frequently experienced beta wave activation within the 25% to 35% range. While the group that ran out of time experienced beta wave activations over a wider range, signaling high variance among beta wave frequencies, the concentrated range of beta wave activation may indicate a certain threshold of beta wave frequency for optimal self-control before the brain is taxed. This conclusion can be drawn because of previous research in which researchers hypothesized that overstimulation of the inhibitory regions of the brain may impair self-control functioning by exhausting pyramidal neurons of the cortex and thus diminishing the neurons' capacity for information processing (Sherman et al., 2016). This research background allows for the interpretation that this study's significant range of beta wave activation levels indicates the range of activation levels where self-control is determined be maximized. On the contrary, insufficient stimulation of the prefrontal cortex portrayed by beta wave activation levels below the optimal threshold may similarly lead to self-control failure, demonstrating the necessity of appropriate stimulation of the prefrontal cortex (Diamond, 2012; Heatherton & Wagner, 2011).

Because no correlations were found between an individual's self-report scores of the amount of self-control they perceived themselves as possessing and their decision during the intertemporal choice task, the results of the test indicate that adolescents' failure to predict their own self-control may further contribute to low self-regulation.

Discussion

Limitations

As mentioned previously in methodology, participants constituted a convenience sample. While the participant was asked to complete the self-report survey on their own time, the intertemporal choice task required attendance in person. This condition narrowed the time frame participants could complete the task as the available times for task completion included before school, after school, and midday. Due to the flexibility offered to participants regarding when they could complete the task, differences in the time-of-day participants chose to complete the task may contribute to variations in the data. For example, a participant who chose to complete the task before lunch may have possessed a stronger desire for the reward of chocolate in comparison to a participant completing the task after school.

Furthermore, another limitation that arises is that participants all consisted of the age group of 16-18 years. There are inconsistencies in the ability to self-regulate in adolescents versus adults that primarily can be attributed to differences in the prefrontal cortex (Chester et al., 2016; Casey & Caudle, 2013). Contrary to the popular notion that a lack of self-control can be wholly accredited to an underdeveloped prefrontal cortex, when exposed to emotional cues, children demonstrate a similar ability to overcome impulses as in the absence of emotional stimuli. Adults likewise performed similarly in a self-control task regardless of the presence or

absence of various social cues. Adolescents, however, demonstrated a decline in self-control when presented with emotional cues (Casey & Caudle, 2013; Somerville et al., 2011). The comparatively low levels of self-control adolescents demonstrate in the presence of emotional stimuli can be attributed to the rate of development of the ventral striatum surpassing the rate of development of the prefrontal cortex during adolescence (Casey & Caudle, 2013). The ventral striatum is heavily involved in reward processing; specifically, the ventral striatum coordinates an individual's response to reward stimuli (Roitman et al., 2005; Báez-Mendoza & Schultz, 2013). In a study measuring activity in the ventral striatum during a task evaluating suppression of temptations in the presence of three types of stimuli (negative, neutral, and positive), it was found that increased activity in the ventral striatum was detected in adolescents who failed to suppress their responses to emotional stimuli (Casey & Caudle, 2013). These findings contend with the assumption that the absence of self-control frequently detected in adolescents is solely attributed to an underdeveloped prefrontal cortex. Rather, researchers Casey & Caudle (2013) have proposed alternative justifications involving development of cortical regions centering on emotion:

> In contrast, these studies have revealed a unique sensitivity to motivational cues during adolescence that appears to challenge the less mature cognitive control systems when called upon simultaneously in tasks that involve inhibiting attention or actions toward potential incentives. Accordingly, developmental differences in self-control arise because of maturational constraints of developing brain circuitry and the strengthening of the connectivity between these interacting brain systems with experience (Liston et al., 2006). (Casey & Caudle, 2013)

Thus, the origin of self-control failure is not solely dependent on level of development of the prefrontal cortex. Rather, additional elements such as adolescents' heightened responses to emotional stimuli also play a role in the ability of an individual to self-regulate, revealing the need to reproduce this study on a wider range of age groups in order to account for the varying stages of development of the prefrontal cortex.

Implications

Understanding the impact of beta waves on self-control in the prefrontal cortex allows for further insight into how self-control can be improved. In particular, individuals with impulse control disorders, a group of psychiatric disorders characterized by impulses to harm oneself or others, may benefit greatly from a more extensive understanding of the neurological processes that drive such impulses (Schreiber et al., 2011). Currently, EEGs have increasingly been used to evaluate the relationship between brain wave activation and neurological processes to further research on improving neural disorders (Mendez & Brenner, 2006). One significant mechanism EEGs prove valuable for is the use of neurofeedback. Neurofeedback involves the use of feedback signals to condition the brain to produce desirable brain wave patterns (Klimesch, 1999; Marzbani, 2016; Lévesque 2006). Neurofeedback could "train" a subject to demonstrate more self-control by recognizing optimal brain wave thresholds (Lubar, 1995). This has been done in individuals to improve cognitive and memory performance, specifically with the use of alpha/theta combinations to enhance long-term memory (Klimesch, 1999). Alpha/theta combinations have often been found in conjunction when evaluating cognitive performance in relation to neural activity. In particular, alpha/theta combinations are correlated with changes in evidence accumulation. Evidence accumulation during decision-making details the concept that

there is a certain threshold for evidence or attributes that individuals find attractive for a particular decision. Each additional attribute may carry varying amounts of weight, and the buildup of such attributes may surpass the individual's decision-making threshold, thus enabling the individual to act on their decision (Rangel et al., 2008). Hajihosseini & Hutcherson explain this phenomenon through a scenario an individual faces when making a decision on diet:

> For example, when we decide what to eat for lunch, we might consider attributes like how tasty or healthy a food is, our dieting goals, current hunger levels, and so forth. Each of these attributes constitutes evidence for or against eating the food, with different attributes given differential weight depending on a person's momentary goals. To choose, current models assume that noisy neural representations of this attribute-based evidence may serve as the input to a process of sequential evidence accumulation (EA) over time until sufficient evidence has accumulated to pass a decision threshold (Forstmann, Ratcliff, & Wagenmakers, 2016; Gold & Shadlen, 2007). (Hajihosseini & Hutcherson, 2020)

Increased accumulation of evidence was found to be correlated with a reduction in both alpha and theta oscillations (Hajihosseini & Hutcherson, 2020). Understanding the relationship between alpha/theta combinations and cognitive performance granted researchers the ability to employ neurofeedback treatment to improve focus and concentration in individuals with attention-deficit disorders.

Figure 3

Use of Neurofeedback in Improving Impulse Control (Myndlift, 2018).

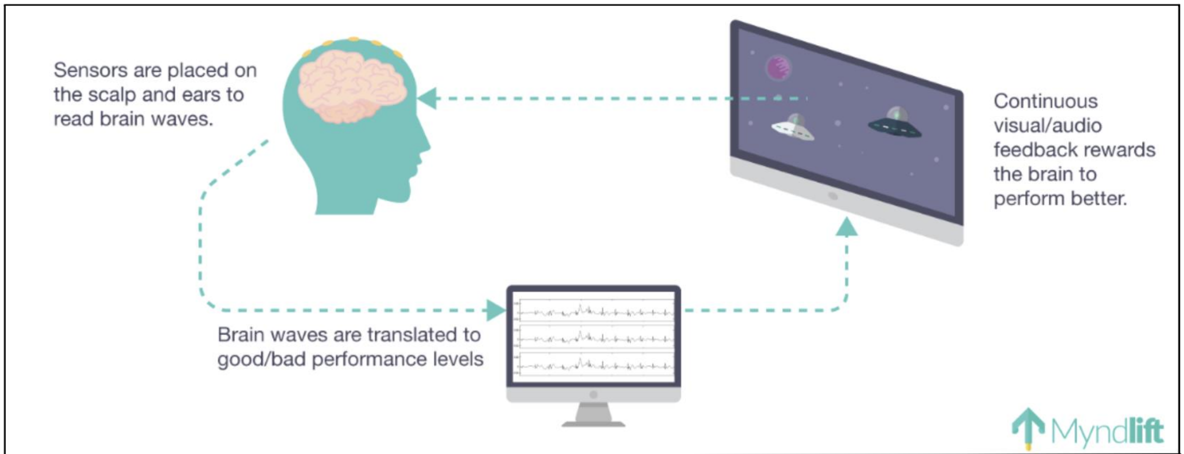


Figure 3: This figure shows the process of neurofeedback, a non-invasive brain treatment able to “train” the brain the improve targeted cognitive processes including focus, concentration, and self-control. Neurofeedback requires the use of neuroimaging techniques to measure the brain wave data of participants as they focus on a behavioral task, then optimize behaviors by providing positive or negative feedback according to performance levels.

Through the process of neurofeedback, behaviors such as focus, concentration, or self-control can be enhanced. Specifically, during a session of neurofeedback targeting improvement in concentration in individuals with attention-deficit disorders, researchers are able to collect the brain wave data of these individual and identify the optimal pattern of alpha wave frequencies that appeared to be present during high levels of focus. Individuals with attention-deficit disorders are frequently found to have abnormal firing of alpha wave levels; thus, researchers monitor alpha wave activation levels in particular during a session of neurofeedback. Participants are then asked to take part in a task that required certain levels of focus, such as watching a movie. The participants are then rewarded with positive or negative feedback according to how well they perform during the task. For example, when the subject is highly concentrated, the task (movie) plays normally. However, when the subject begins to lose focus, a circumstance

reflected by changes in alpha brain wave patterns of the individual, the subject will receive negative feedback in the form of gradual discontinuation of the task, exemplified by fading out the visual or audio (i.e., dimming the sound) components of the movie. By using feedback to reinforce the optimal sequence of brain wave frequencies, focus and concentration can be enhanced. This form of neurofeedback, known as frequency/power neurofeedback, is the most commonly used neurofeedback, in which changing the speed or amplitude of certain brain waves or combinations may treat neurological disorders (Marzbani et al., 2016). Similarly, beta/theta combinations have shown potential for enhancing self-control for individuals with impulse control disorders (Roohi-Azizi et al., 2017). For instance, recognizing an optimal point of beta wave activation, such as activation levels between 25% and 35%, combined with low theta activation, may reinforce self-control processes.

This study's investigation of optimal beta activation levels could allow for significant development in the use of neurofeedback to improve self-control, particularly for individuals who may struggle with impulse control disorders. With more conclusive research on the mechanisms that can improve self-control with respect to brain wave functioning in the prefrontal cortex, researchers are able to understand and employ neurotherapies that hold great potential for enhancing self-control.

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